Molecular Electronics (Moletronics)

William L. Warren, DARPA – DSO

Christie R. K. Marrian, DARPA - MTO

Moletronics – What's It All About?

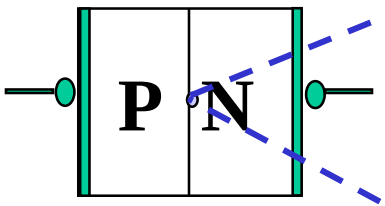
Replace conventional components with self-assembled functional molecules

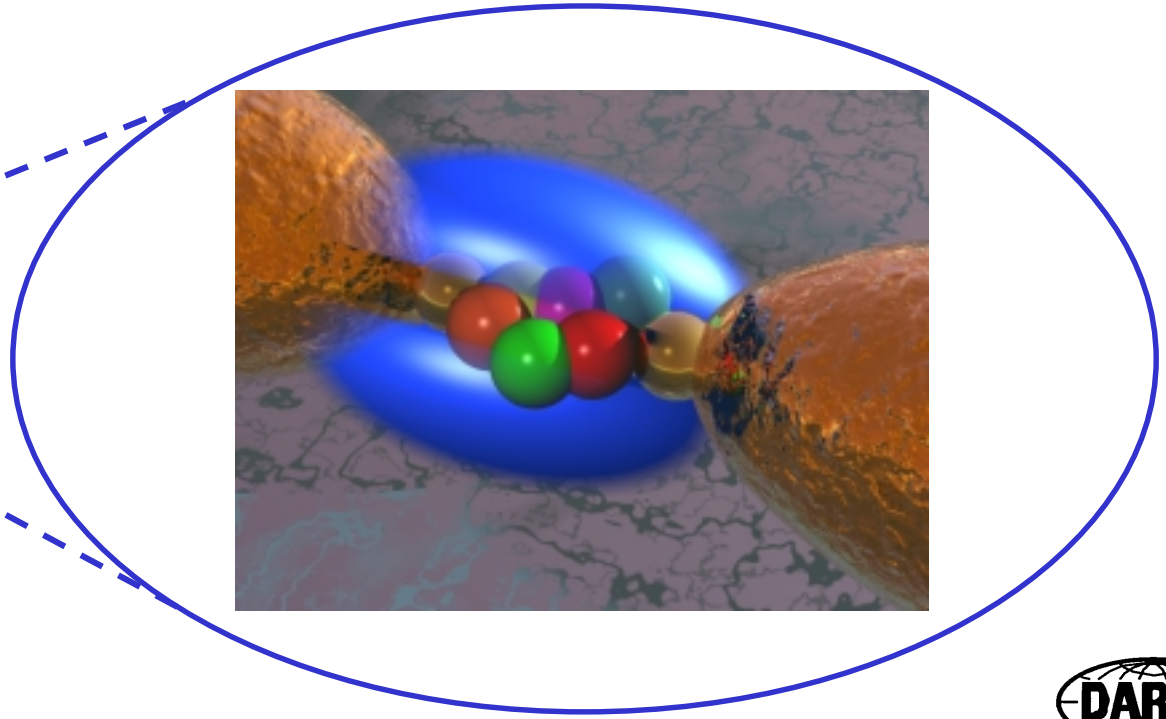
P-N Diode

90,000 nm^2

Molecule

9 nm^2





Information Content

- One color photo ~ 10^5 b
- Average book ~ 10^6 b
- Genetic code ~ 10^{10} b
- Human brain ~ 10^{13} b
- Annual newspapers ~ 10^{14} b
- Library of Congress ~ 10^{15} b
- Human culture ~ 10^{16} b
- Annual television ~ 10^{18} b

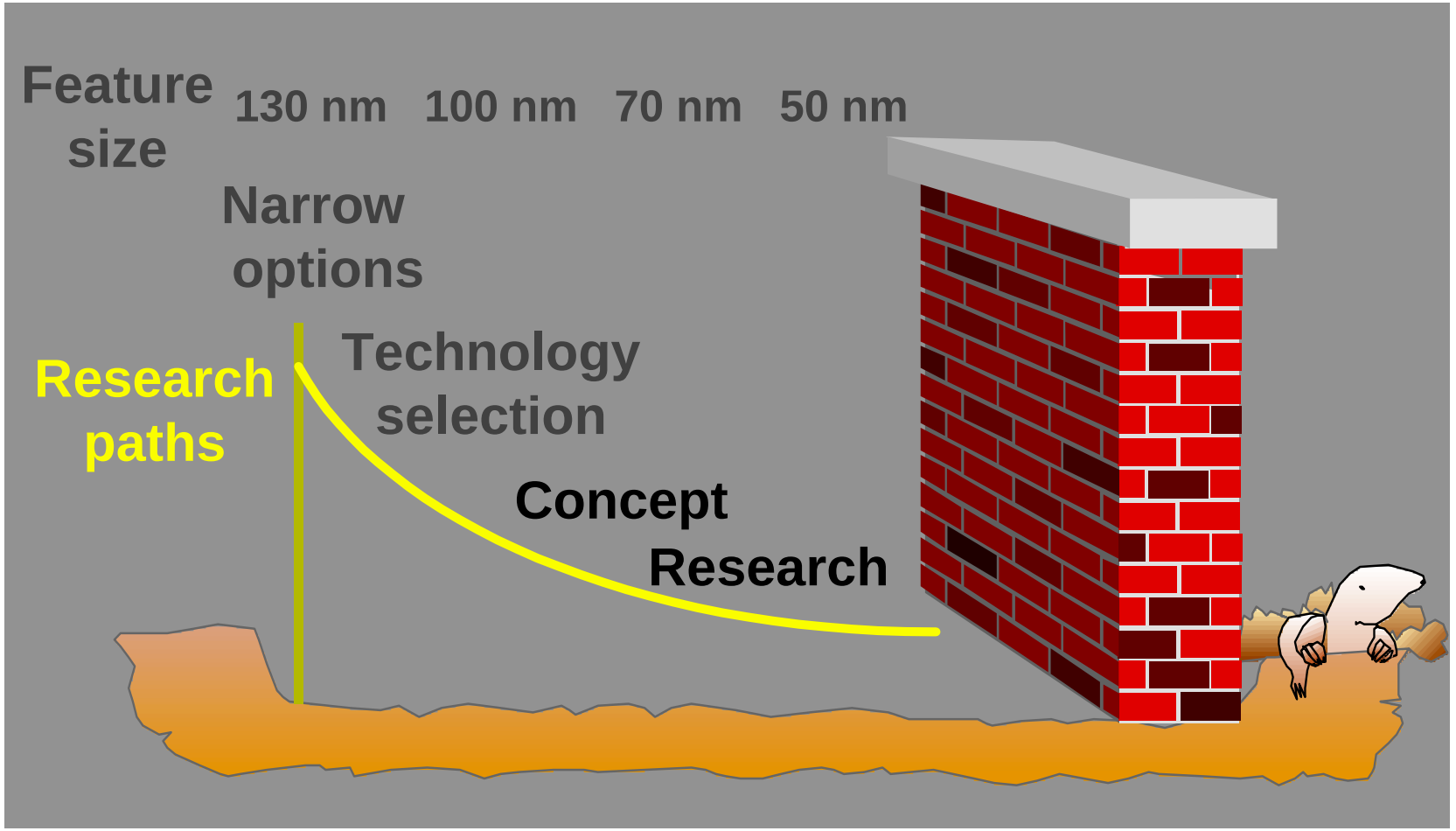
Total ~ 10^{20} bytes

Imagine if we had a mole (> 10^{23}) of bytes!!

DARPA

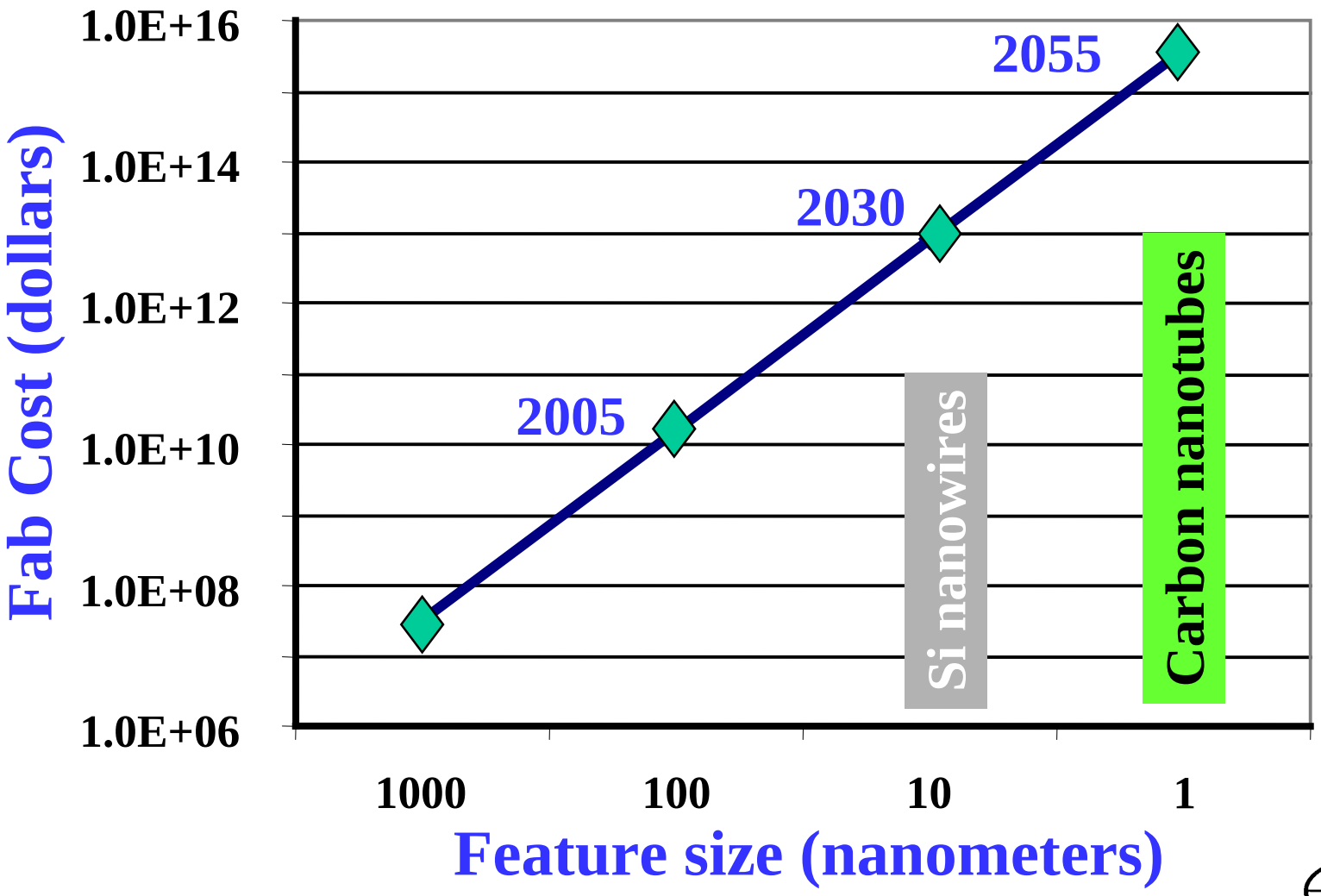
Moletronics – An Underground Operation

Technical hurdles for "slice and dice" Si CMOS



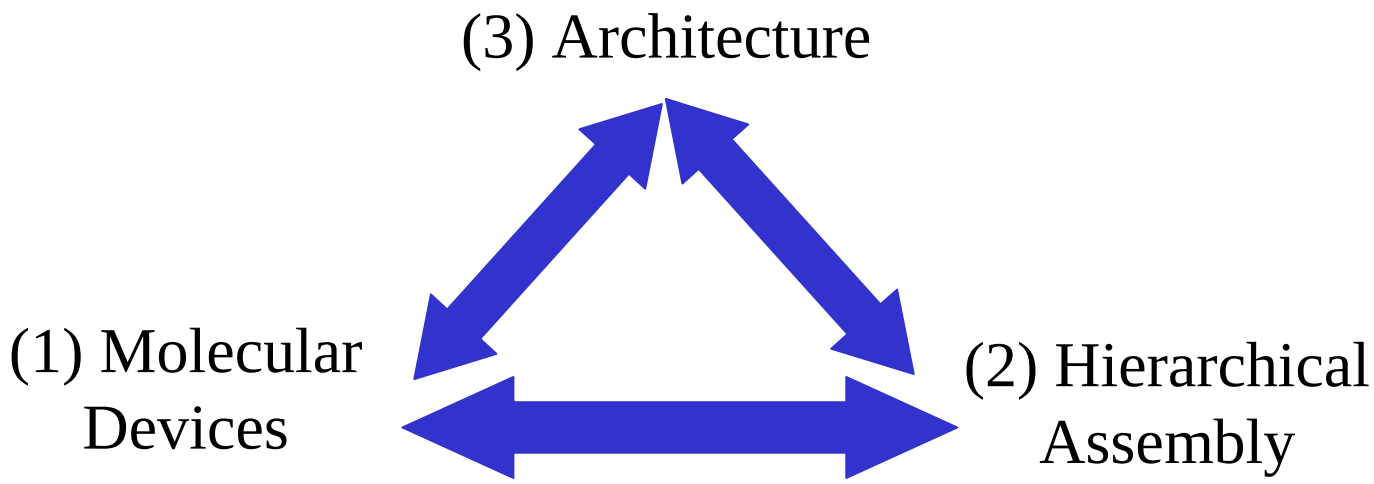
Moletronics Overcomes Fabrication Costs for Lilliputian Computers

Moore's First Law vs. Moore's Second Law

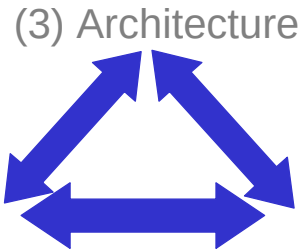


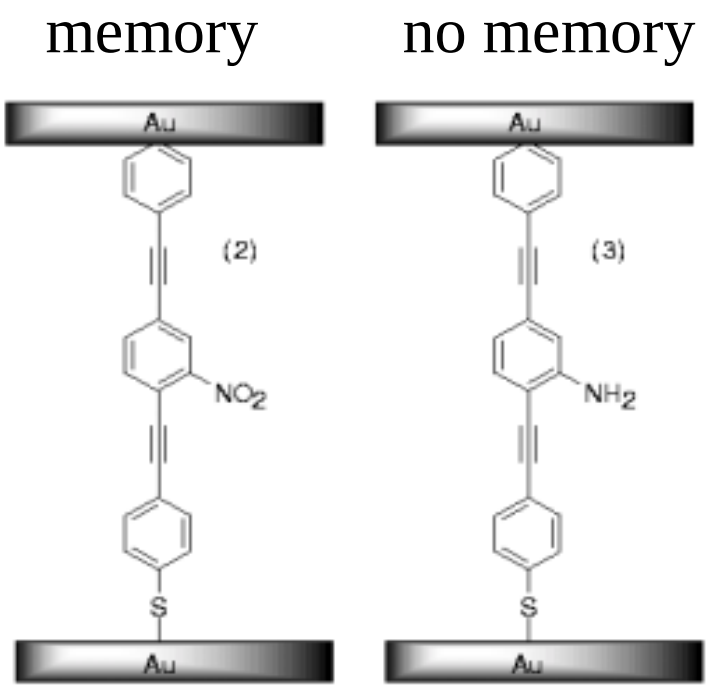
Moletronics: Re-Inventing the IC at Molecular Densities

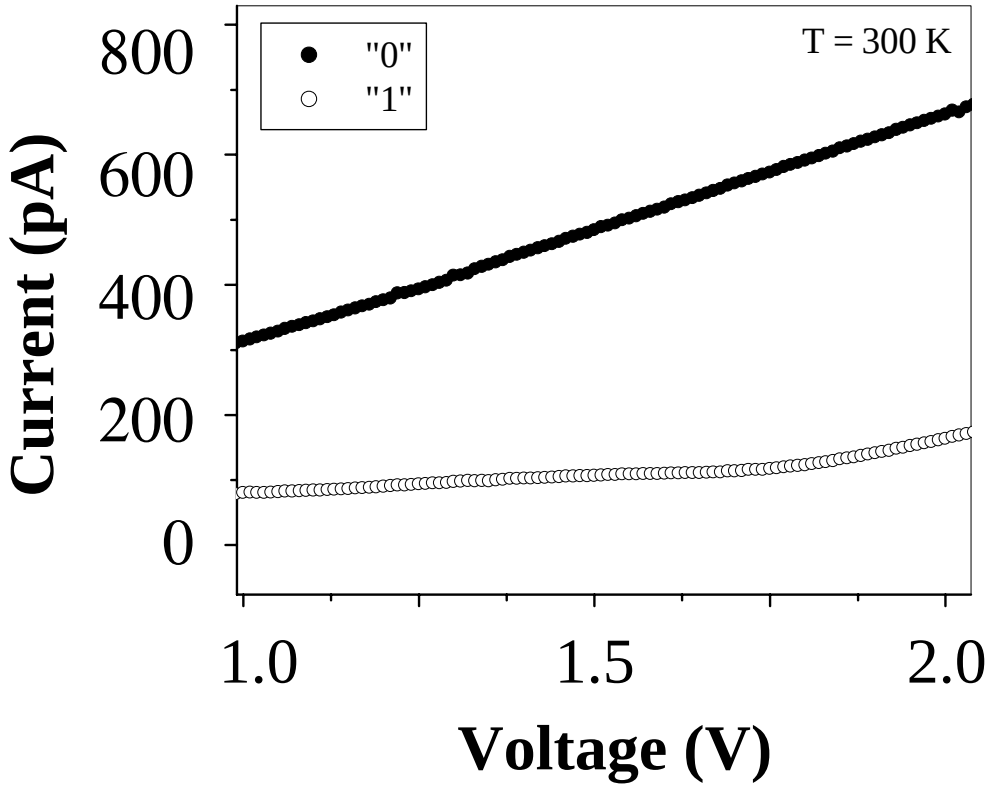
- **Goal**
  - Demonstrate computational functionality and I/O in ***scalable*** molecular systems using hierarchical assembly at insanely high device densities
- **Moletronics Approach**



The Need to Chemically Design Electronic Functionality



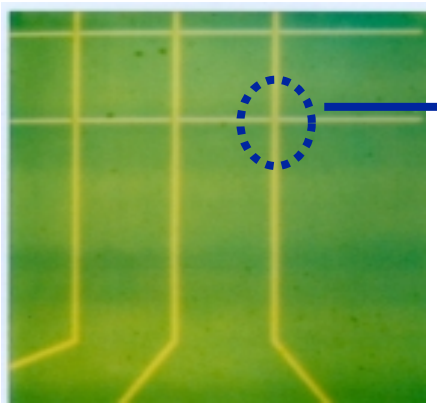


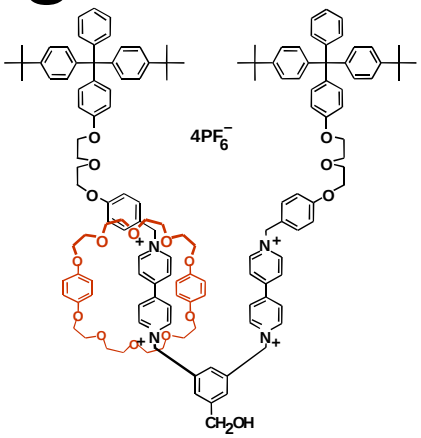


Yale University, Rice University

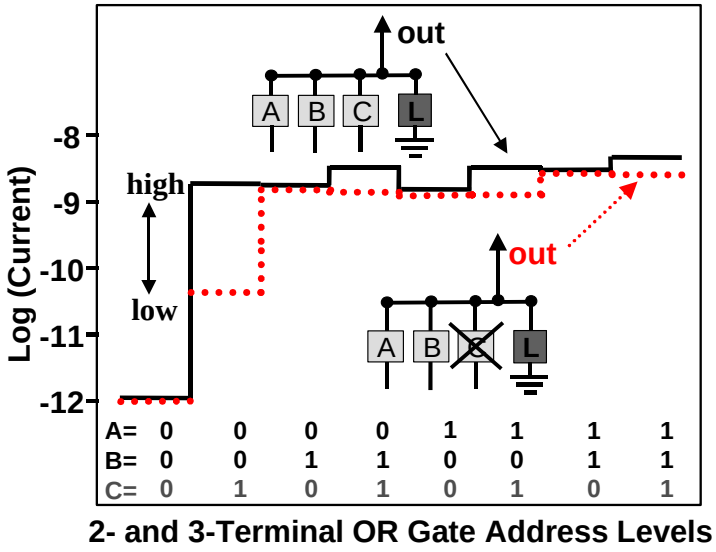
DARPA

“OR” and “AND” Gates Have Been Fabricated Using Molecules



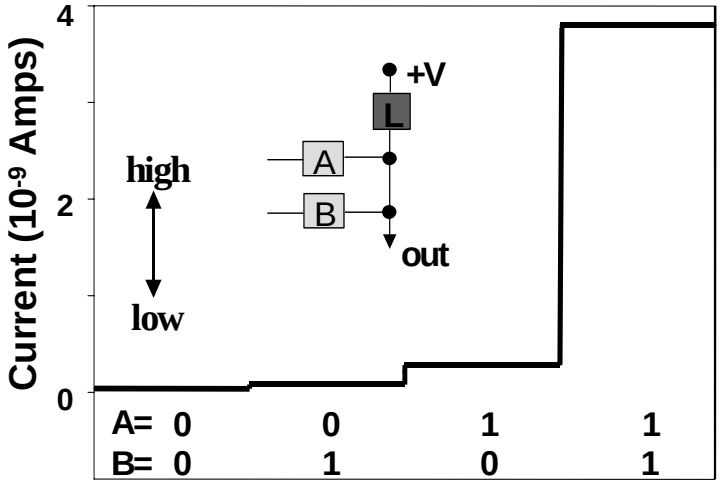


Moletronic OR Gate



2- and 3-Terminal OR Gate Address Levels

Moletronic 2-Input AND Gate

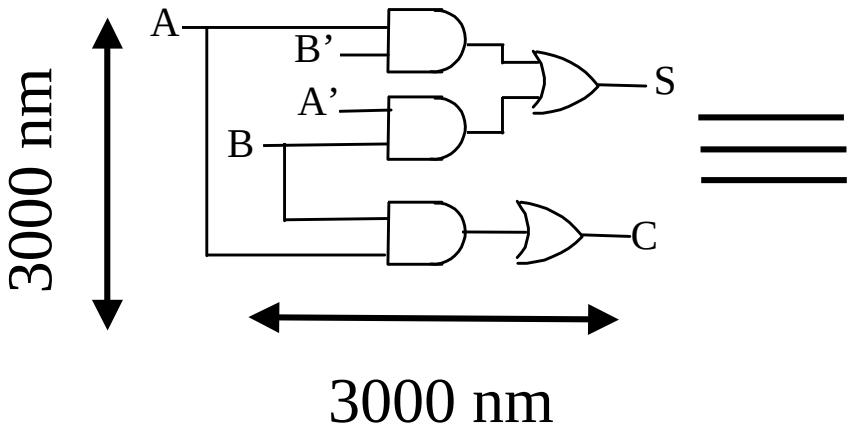


AND Gate Address Levels

UCLA, HP Labs

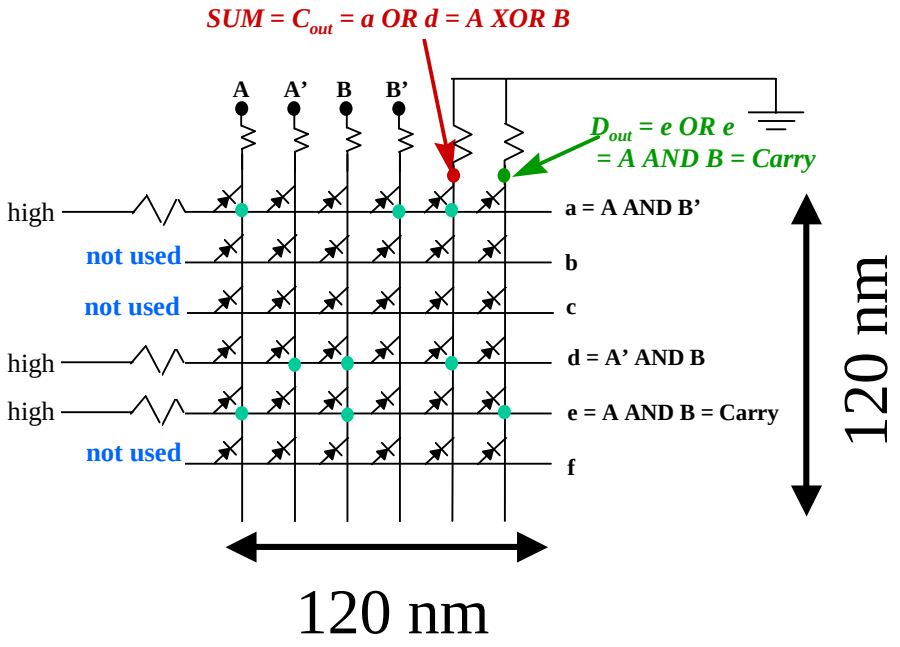
Mountains Into Molehills

Conventional Si

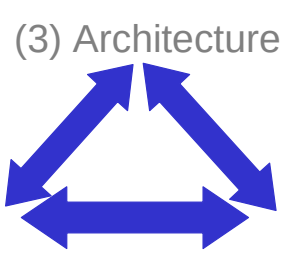


Logic gates ~ 3 transistors

Moletronics

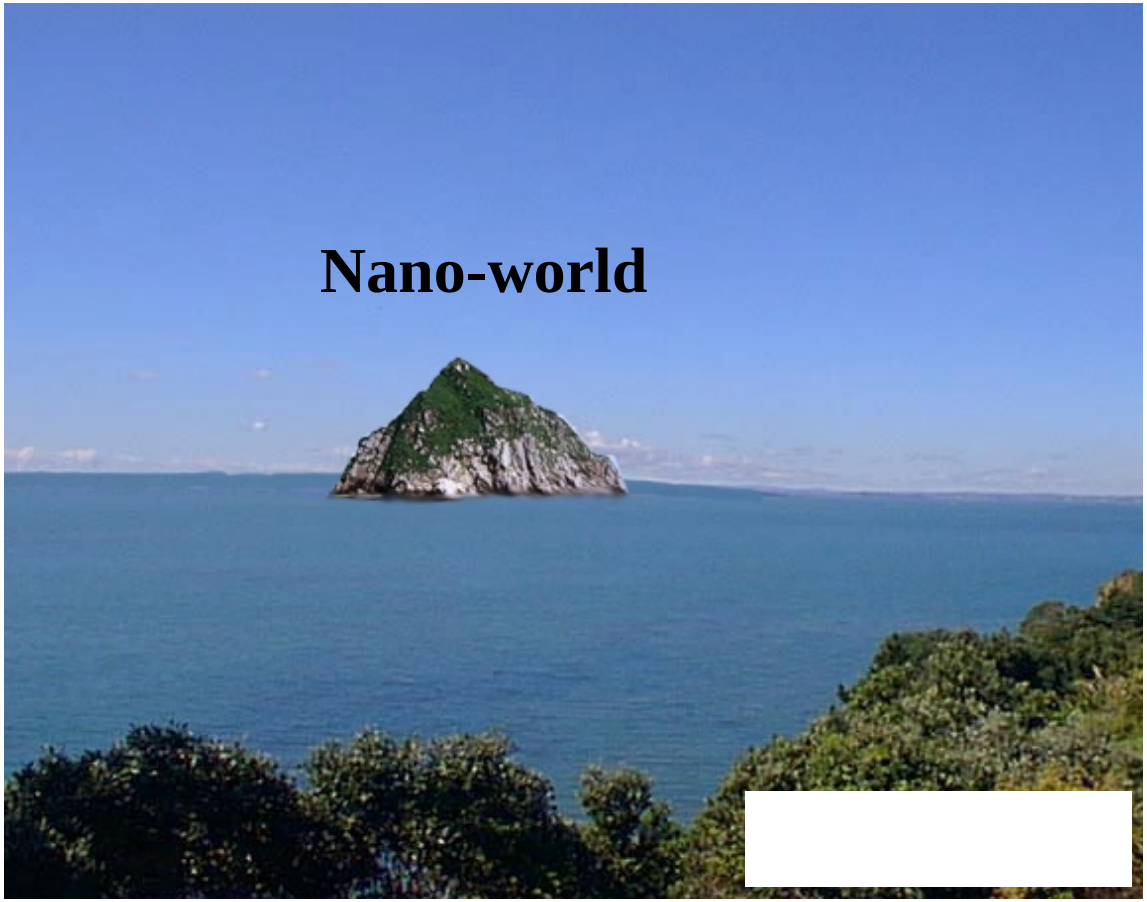


10 nm lines, 20 nm pitch



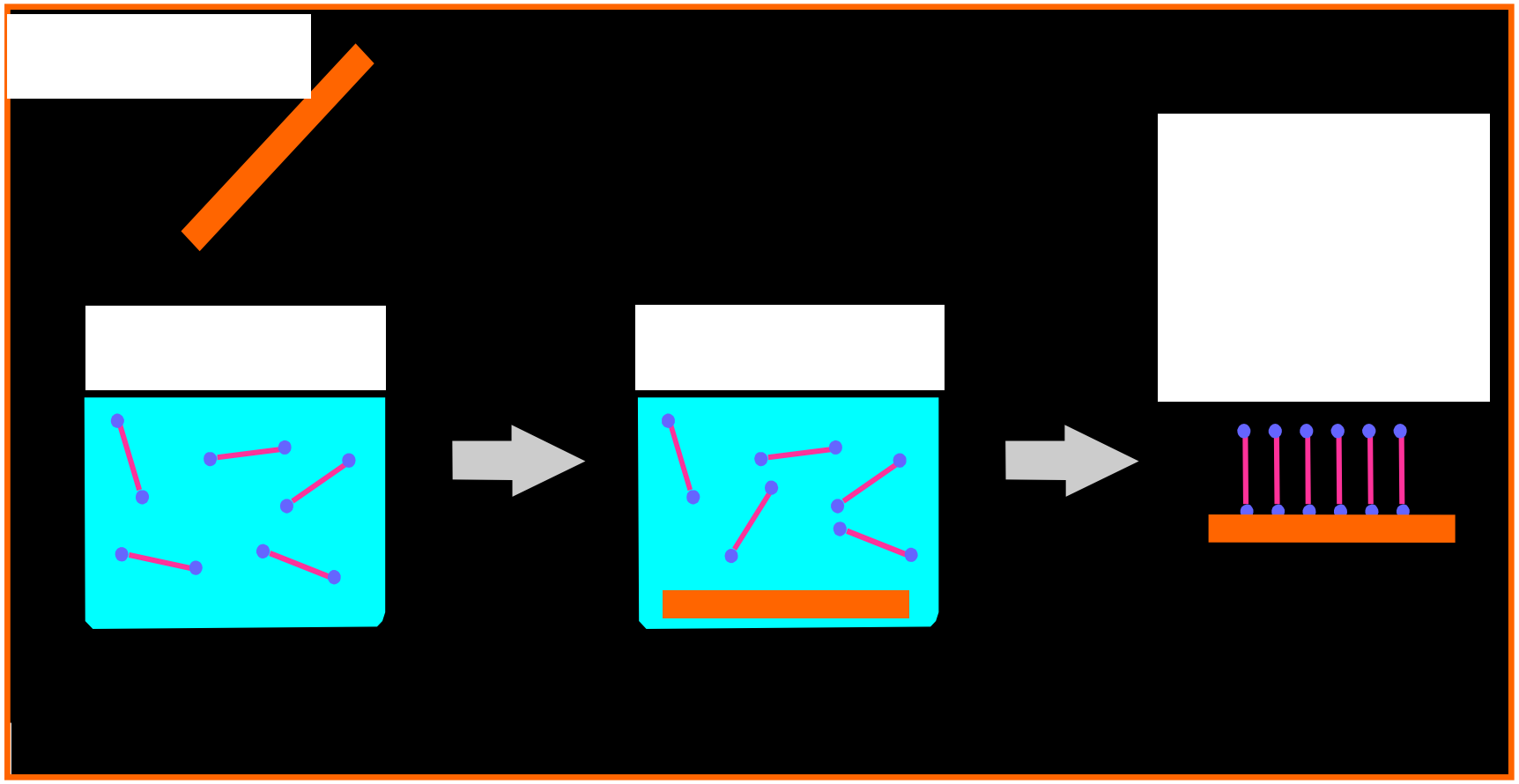
Hierarchical Assembly

Crossing the Chasm from the Nano to the Micro-World



Self-Assembly

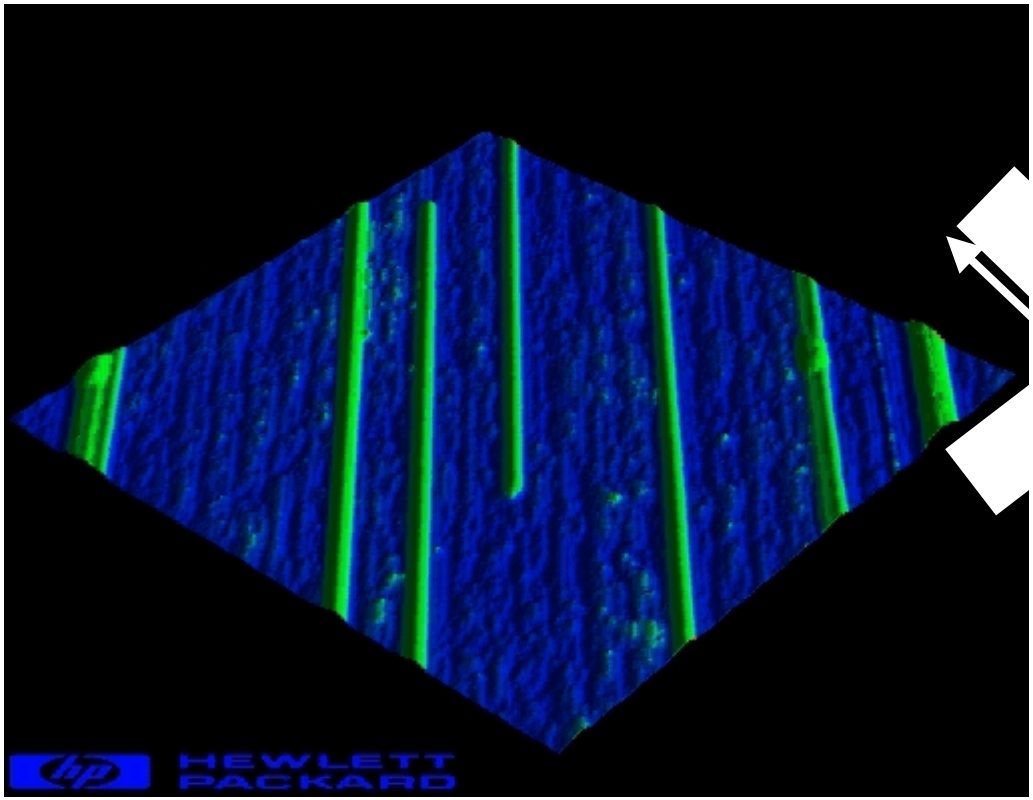
Process in which structures naturally assemble into desired patterns based on thermodynamic equilibrium

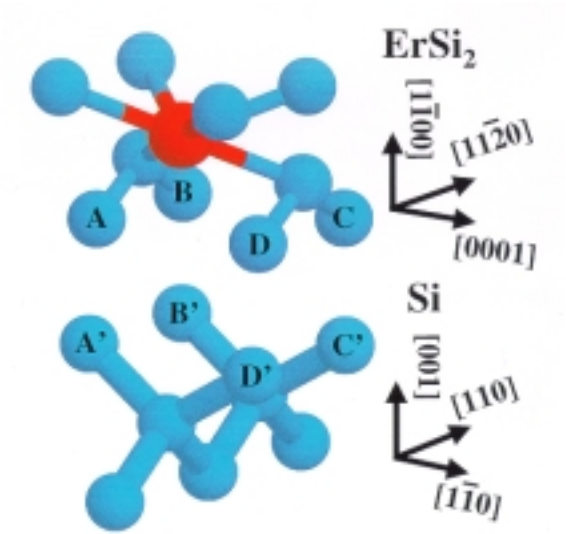


Self-Assembly Makes Aligned Arrays of 2 nm Nano-Wires

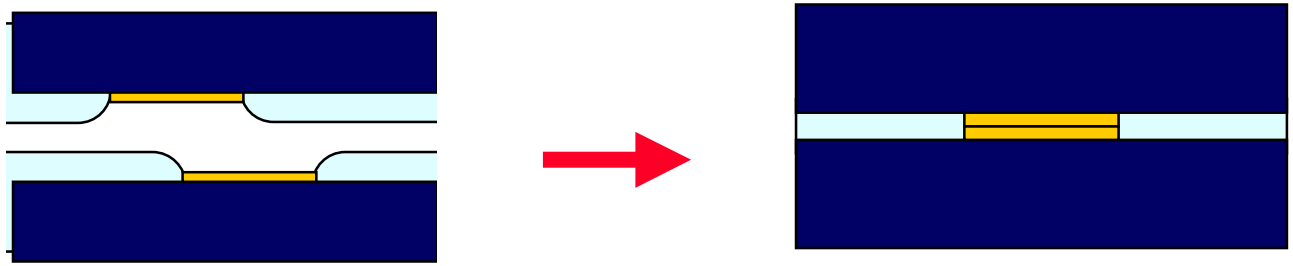
Assembly dictated by anisotropic lattice mismatch with Si

Unbelievable – 10 atoms wide,
2 atoms high, microns long!

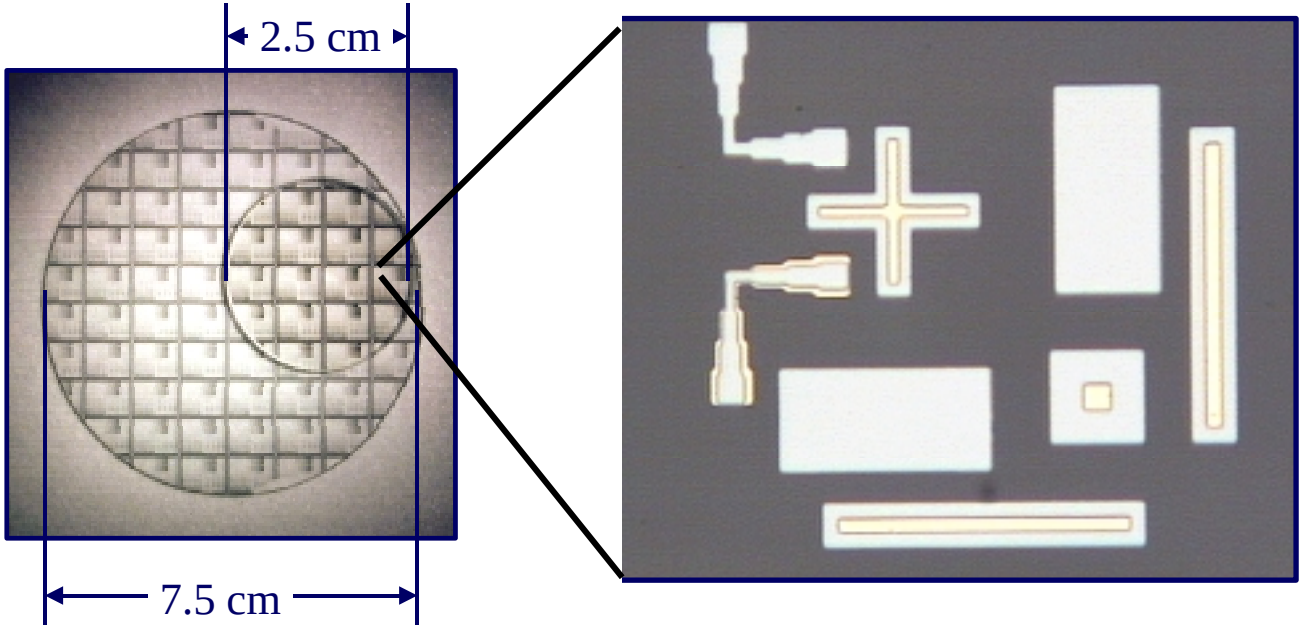




Assembly of Cross-Bars Using Water (Hydrophobic/Hydrophilic Interactions)



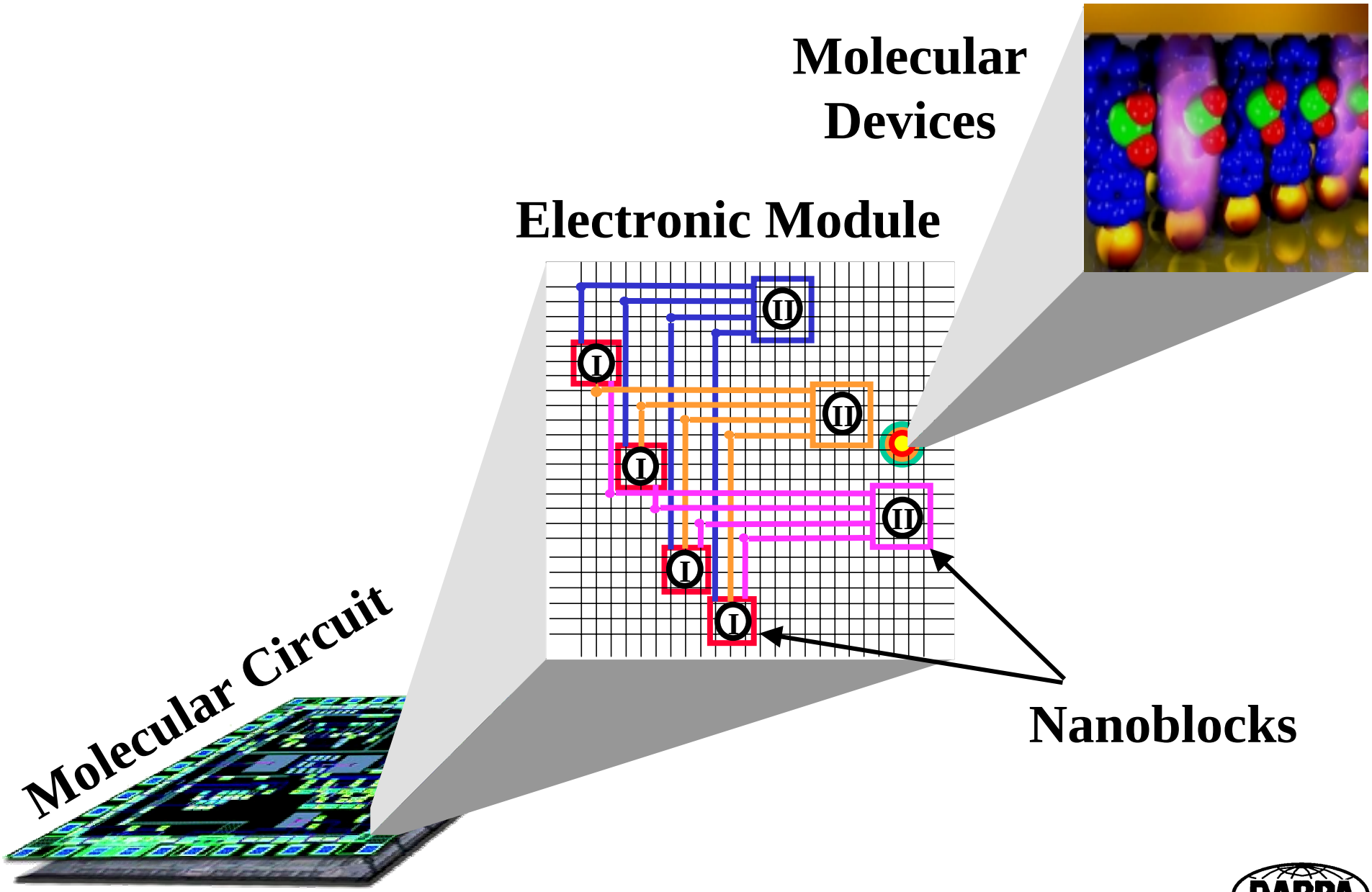
- Chip border used as primary driving force for alignment
- Better than 1 μm alignment achieved across a 2.5 cm substrate
- Local alignment anticipated to be at least 10's of nm



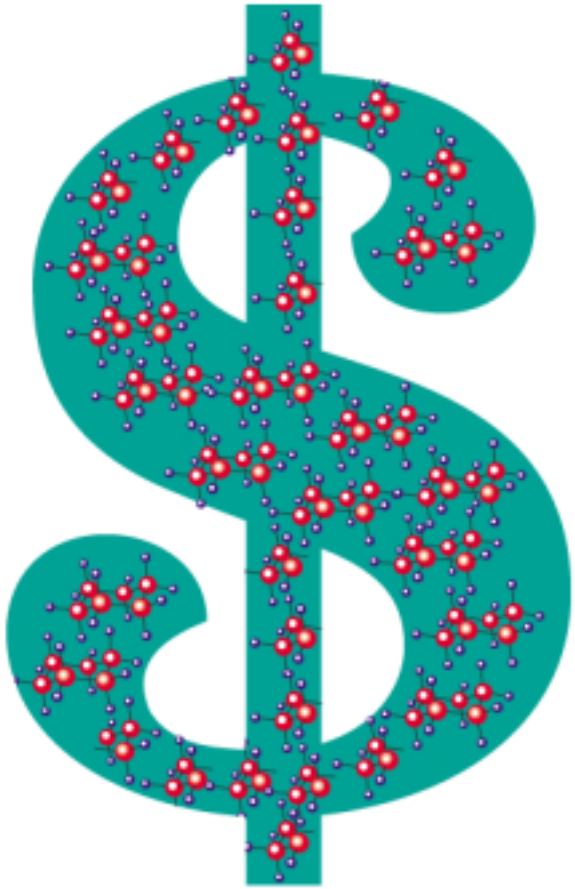
Penn State

DARPA

Hierarchical Assembly

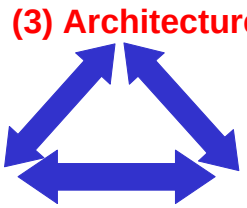


Moletronics Objective



Hierarchical-Assembly Will Reduce The Cost of Electronics Manufacturing

DARPA



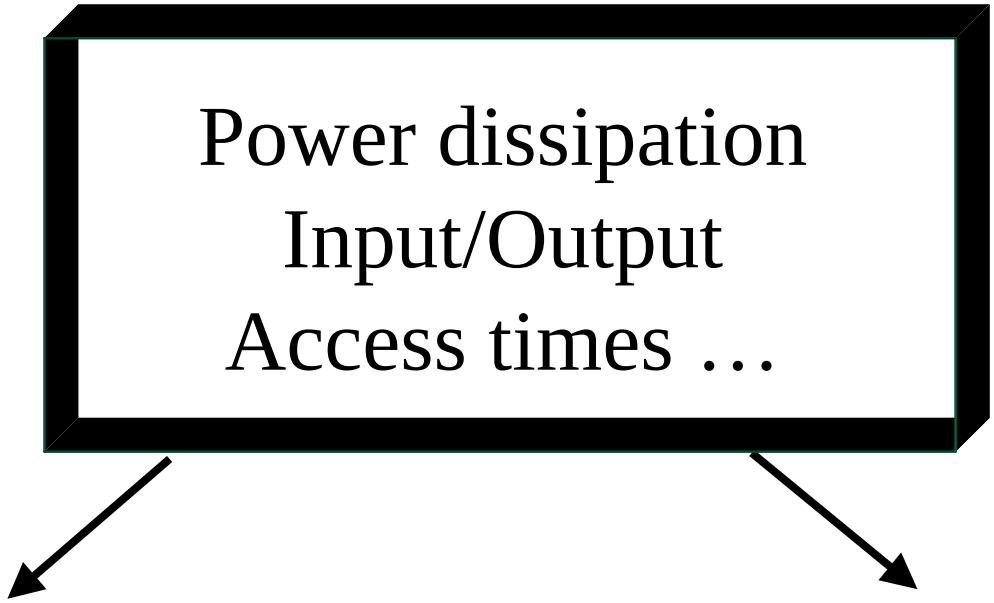
Architecture and Defects

When a single defect could kill ‘ya

When defects won’t kill ‘ya

- Scalable architectures
- Defect tolerance
- Algorithm development

System Architecture Scalability



Supercomputer

10^{12} devices in 1 cm^2

10^{12} Hertz switching speed

~ 10^4 Watts!

Nanocomputer* ~ Pentium III

10^9 devices in 10^{-3} cm^2!

10^9 Hertz

~ 10^{-2} Watts

*Assumes $10^{12}/cm^2$ device density & 2.5 kT/operation

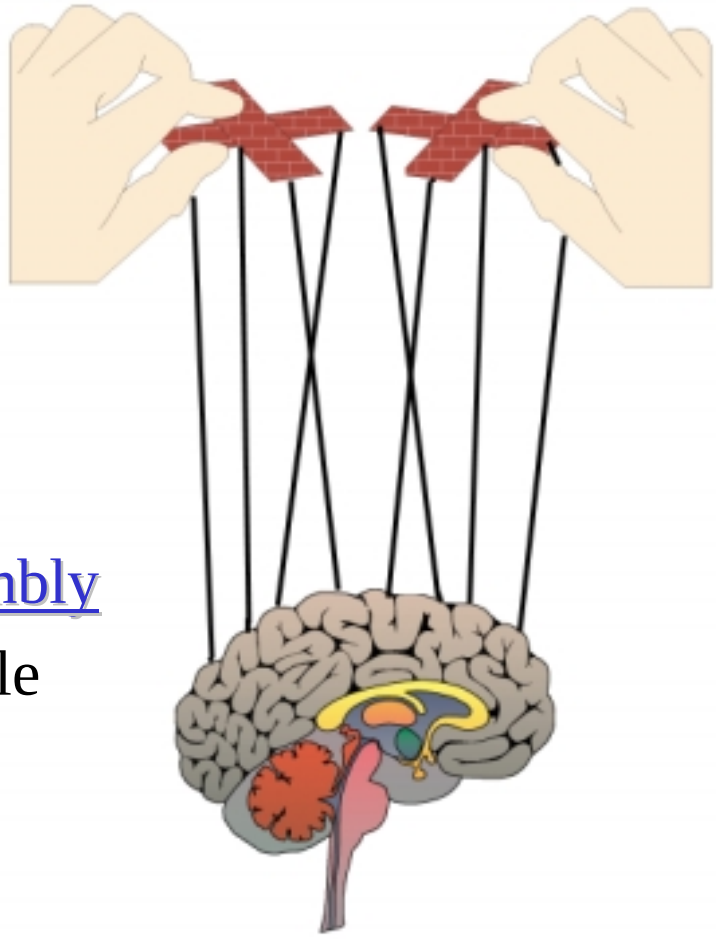
A Molecular Computer that Needs to be "Taken to School"

Old Way: Precision Design and Build

Design - Build - Compile

New Way: Directed Design and Self-Assembly

Build - Measure - Reconfigure - Compile

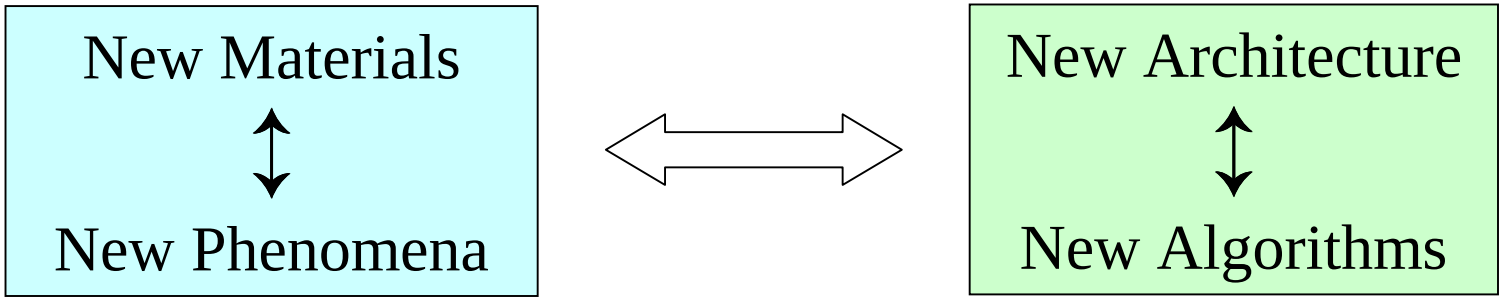


DARPA

Comparisons Between Si CMOS and Moletronics

Properties	Si CMOS	Moletronics
Fabrication	Lithography	Hierarchical assembly
Defined properties?	Yes	No
Defects?	No	Yes
Power	Central	Distributed
Approach	Top-down	Bottom-up Top-down

Conclusions



(bottom up)

(top down)

Molecular/nano materials
Self-assembly
Hierarchical assembly
.
.
.

Multi-state systems
Defect/fault tolerance
Algorithm development
.
.
.